

# SPACE-BASED RANGE SAFETY AND FUTURE SPACE RANGE APPLICATIONS

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## ABSTRACT

The National Aeronautics and Space Administration (NASA) Space-Based Telemetry and Range Safety (STARS) study is a multiphase project to demonstrate the performance, flexibility and cost savings that can be realized by using space-based assets for the Range Safety [global positioning system (GPS) metric tracking data, flight termination command and range safety data relay] and Range User (telemetry) functions during vehicle launches and landings. Phase 1 included flight testing S-band Range Safety and Range User hardware in 2003 onboard a high-dynamic aircraft platform at Dryden Flight Research Center (Edwards, California, USA) using the NASA Tracking and Data Relay Satellite System (TDRSS) as the communications link. The current effort, Phase 2, includes hardware and packaging upgrades to the S-band Range Safety system and development of a high data rate Ku-band Range User system. The enhanced Phase 2 Range Safety Unit (RSU) provided real-time video for three days during the historic GlobalFlyer (Scaled Composites, Mojave, California, USA) flight in March, 2005. Additional Phase 2 testing will include a sounding rocket test of the Range Safety system and aircraft flight testing of both systems. Future testing will include a flight test on a launch vehicle platform. This paper discusses both Range Safety and Range User developments and testing with emphasis on the Range Safety system. The operational concept of a future space-based range is also discussed.

## 1. INTRODUCTION

Current space lift launches on the United States Eastern and Western Ranges require extensive ground-based real-time tracking, communications, and command and control systems. These systems are expensive to maintain and operate and are limited to certain geographical areas. Future spaceports will require new technologies to provide greater launch and landing opportunities, support simultaneous missions, and offer enhanced decision support models and simulation capabilities. These ranges must also have lower costs and reduced complexity, while continuing to provide unsurpassed safety to the public, flight crew, personnel,

vehicles, and facilities. Commercial and government space-based assets for tracking and communications offer many attractive possibilities to help achieve these goals. Fig. 1 shows the current primary Eastern and Western Range instrumentation sites (solid lines) and a possible future space-based configuration with fewer ground-based assets (dashed lines). Note that some launch-head ground-based assets are still planned for visibility and rapid response times shortly after liftoff.

The NASA Space-Based Telemetry and Range Safety (STARS) study was established to demonstrate the capability of space-based platforms to provide communications for Range Safety (low-rate, ultra-high reliability metric tracking data, and flight termination commands) and Range User (video, voice, and vehicle telemetry) [1]. The systems under development and testing include new and improved Range Safety and Range User capabilities and technologies to support the envisioned future space range. This paper concentrates on the low-rate, bidirectional Range Safety system and includes a brief summary of the Range User development effort.

During Phase 1, STARS developed and tested a new S-band Range Safety system. A Range User system representative of those on current launch vehicles was also tested. There were seven test flights on an F-15B aircraft at Dryden Flight Research Center (DFRC) (Edwards, California, USA) during June and July of 2003 [2]. These highly dynamic test flights successfully demonstrated the basic ability of STARS to establish and maintain satellite links with the TDRSS and the global positioning system (GPS) and will serve as a baseline for future test flights.

Phase 2 includes enhancements to the S-band Range Safety system as well as a new telemetry system using a Ku-band phased-array antenna to increase the Range User data rates by an order-of-magnitude. Future phases will implement a new Range Safety transceiver system based on current state-of-the-art transceivers and a much smaller, lighter-weight, phased-array Ka-band telemetry antenna on a recoverable hypersonic vehicle. The TDRSS will be the space-based communications link for future STARS testing.

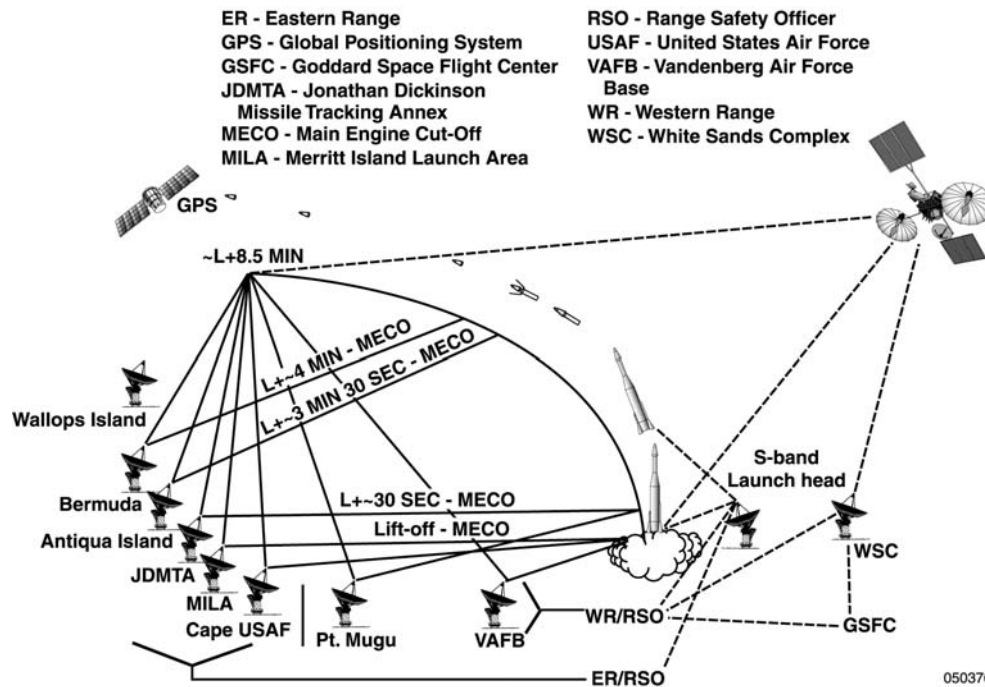


Fig. 1. Space-Based Range and Range Safety – today and future

## 2. PHASE 1 RANGE SAFETY SYSTEM

The Phase 1 Range Safety system shown in Fig. 2 consisted of an S-band low power transceiver (LPT); a GPS receiver and low noise amplifier (LNA); a command and data handler (C&DH) to collect forward link data from the LPT and GPS receiver and format the data for return link transmission; S-band power amplifiers and transmit and receive bandpass filters (BPF); and antennas for TDRSS receive (RCV), TDRSS transmit (XMT), and GPS receive. The Phase 1 configuration is shown in Fig. 2, and included two sets of TDRSS and GPS antennas located on the top and bottom (indicated by dashed lines) of the aircraft and connected to the rest of the system by hybrid couplers and a power divider.

The Range Safety forward link was designed to the requirements for an analog flight termination system (FTS) specifying 95 percent spherical coverage and a 12-dB link margin [3]. A digital FTS may have different requirements for comparable performance and reliability.

Fig. 3 shows a simplified data flow diagram. In conjunction with the TDRSS link, an S-band launch-head transmit and receive system was used to supplement close-in coverage.

The launch head and TDRSS forward link used different pseudorandom noise (PN) codes for simultaneous transmission and reception of launch-head and TDRSS links [4]. The LPT includes four receivers: two that receive launch-head PN-encoded data and two that receive TDRSS PN-encoded data. Hybrid couplers allow the in-phase and out-of-phase upper and lower antenna combined outputs to feed each receiver, Fig. 4.

The 400-bps forward link data comprise frame synchronization, frame counter, and command word information. The command word system included digital words representing standard analog FTS monitor, arm, and terminate commands. A custom programmable logic device (PLD) design generated the forward link data at the DFRC Mission Control Center. The data were then sent to the launch head and TDRSS forward link transmitters.

The Range Safety return link contained status and data from the LPT, C&DH, and GPS receiver. The data include receiver estimates of the ratio of bit energy to noise power spectral density ( $E_b/N_o$ ), average Doppler, hardware temperatures, FTS commands received, FTS status, frame synchronization, frame counter, GPS satellite, and GPS receiver performance data.

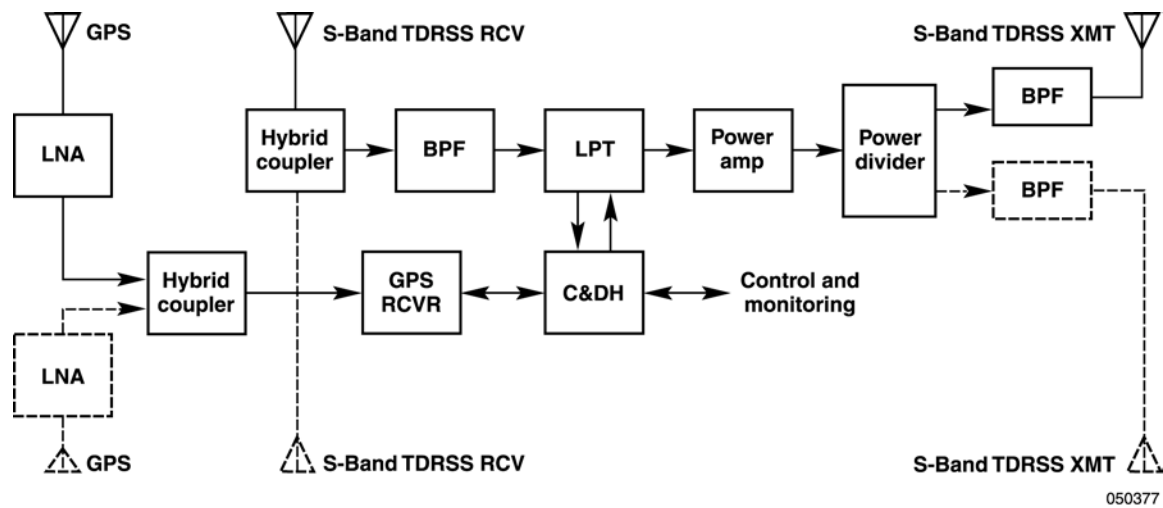


Fig. 2. Phase 1 Range Safety system

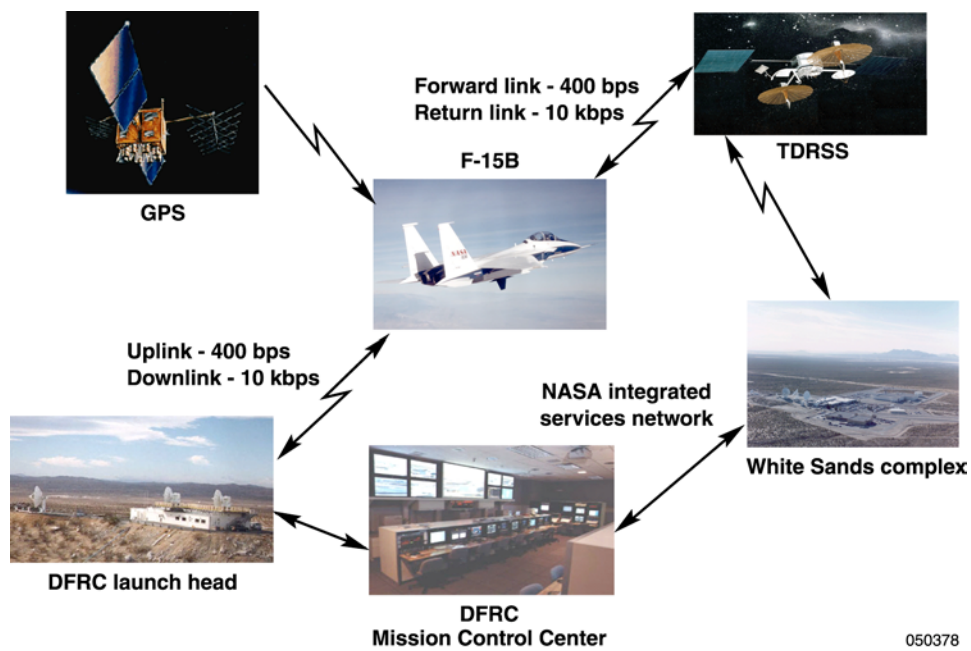


Fig. 3. Range Safety data flow

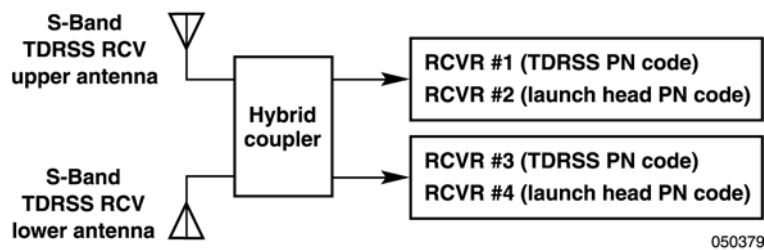


Fig. 4. Range Safety system receiver configuration

The initial series of aircraft flight tests were completed in the summer of 2003. Primary objectives were to verify forward link performance during simultaneous transmission and decoding of Range Safety commands by way of both the TDRSS and launch-head links, verification of transition from launch head to TDRSS during over the horizon flights, relay of GPS position information, and quantifying link margins for both the Range Safety forward (command) and return (status) links.

The Range Safety system met the minimum flight test objectives. Hundreds of commands were successfully sent by way of TDRSS and launch-head forward links. These were decoded in the Range Safety system onboard the aircraft and the FTS status and GPS position were successfully monitored by way of the

Range Safety return link. The system performed well during highly dynamic maneuvers and all forward link commands sent to the vehicle were successfully interpreted. The system return link margin was approximately 2 to 3 dB less than expected, however, important lessons were learned for Phase 2.

### 3. PHASE 2 RANGE SAFETY SYSTEM

The Phase 2 Range Safety system design incorporates lessons learned during the Phase 1 flight tests. The LPT, GPS receiver, and C&DH were integrated into a single unit, shown in Fig. 5, called the Range Safety Unit (RSU). Encryption was implemented on the forward link and Reed-Solomon encoding was implemented on both forward and return links to enhance bit error rate.



Fig. 5. Range Safety Unit

The RSU system was configured to provide real-time video during the Virgin Atlantic (Sussex, United Kingdom) GlobalFlyer (Fig. 6) world record flight. The return link data rate was 57 kbps or 114 kbps, depending on available TDRSS link margins, and controlled from switches in the cockpit. The forward link was not used. There was a single S-band antenna on top of the starboard boom of the GlobalFlyer. The system used a video data compressor to convert phase alternation by line (PAL) video to compressed digital video, which was then relayed by way of TDRSS to the White Sands Complex (Las Cruces, New Mexico, USA) and sent over land lines to the GlobalFlyer control room for display and distribution over the Internet. The STARS video was used in conjunction with an Iridium (Bethesda, Maryland, USA) voice link during pilot interviews throughout the mission. The RSU performed well during the nearly three-day flight. There were no environmental problems and the measured Eb/Nos exceeded the predictions by 3 to 5 dB.

#### 4. PHASE 1 RANGE USER SYSTEM

The Phase 1 Range User system, shown in Fig. 7, consisted of an S-band TDRSS transmitter, data multiplexer, power divider, power amplifiers, and two TDRSS transmit antennas located on the top and bottom of the F-15B airplane. The analog video and voice were digitized, compressed, and multiplexed with the pseudorandom data and IRIG-B time inputs [based on Universal Time Coordinated (UTC) derived from GPS time] to create a standard IRIG-106 data stream [5,6]. The data multiplexer format was programmable to 125, 250, or 500 kbps; video was included only in the 500-kbps format. The primary objective to transmit vehicle Range User data to the ground by way of TDRSS for relay to DRFC with at least a 3-dB link margin was satisfied.



Photo courtesy Virgin Atlantic.

Fig. 6. GlobalFlyer

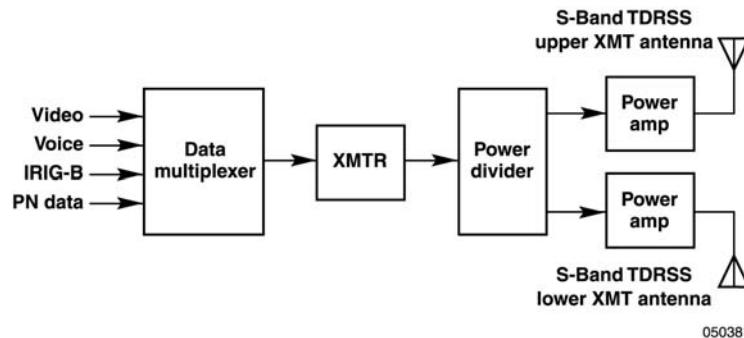


Fig. 7. Phase 1 Range User system

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## 5. FUTURE PLANS AND CONCLUSIONS

Phase 2 flight testing on a high-performance aircraft is scheduled for 2006 contingent upon funding availability. These tests will measure the system data latency and evaluate the performance of the Range Safety Unit with multiple Tracking and Data Relay Satellites and an updated return-link antenna. A major goal is to determine if a lower link margin with two simultaneous satellite links provides performance equivalent to current analog flight termination systems. A Ku-band phased-array antenna will be used to increase the Range User data rates by an order-of-magnitude.

A sounding rocket test flight of the Phase 2 Range Safety system is currently planned for the fall of 2005. This will be a high-velocity and high-altitude mission to investigate plume effects and the system's performance on a platform representative of an expendable launch vehicle.

The testing to-date indicates that the space-based range safety concept is feasible. Phase 1 flight testing successfully sent and processed over 300 flight termination system commands. Global positioning system metric tracking data was transmitted from the vehicle and received, processed, and displayed at the control center. The Range User telemetry link margins for various data rates met or surpassed the predicted margins. The Phase 2 Range Safety system flown on GlobalFlyer exceeded expectations and demonstrates that the technology has possible additional applications in the area of suborbital vehicles and related air traffic control. These applications could include operations on other celestial bodies including the planned NASA Exploration Mission objectives on the moon and Mars.

The ultimate goal of an operational space-based range is the development and implementation of flexible, reliable, low cost, over the horizon space-based range safety systems. NASA and the United States Air Force have been working together through various forums such as the Advanced Range Technologies Working Group to develop roadmaps for the Operational System Design, Development, Concept of Operations, and Range Certification. The development and implementation of the future space-based range concept is critical for expanding government and commercial launch operations in a way that maximizes safety and minimizes related costs thereby enabling the growth of the commercial launch industry.

## 6. REFERENCES

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